CHARLES DARWIN UNIVERSITY	**Family Name**	
	Given Names	
	Student Number	
	Teaching Period	Semester 1, 2016

FINAL EXAMINATION	**DURATION**
ENG443 – Reactor Design	Reading Time: **10** minutes Writing Time: **180** minutes

INSTRUCTIONS TO CANDIDATES

This exam consists of five (5) questions totalling 100 marks.

EXAM CONDITIONS

You may begin writing from the commencement of the examination session. The reading time indicated above is provided as a guide only.

This is a RESTRICTED OPEN BOOK examination

Any non-programmable calculator is permitted

One A4 sheet of handwritten/printed double-sided notes permitted

No dictionaries are permitted

ADDITIONAL AUTHORISED MATERIALS	**EXAMINATION MATERIALS TO BE SUPPLIED**
No additional printed material is permitted	1 x 20 Page Book 2 x Scrap Paper

THIS EXAMINATION IS PRINTED DOUBLE-SIDED.

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Problem 1 (15 marks)

Large central power stations (about 1000 MW electrical) using fluidized bed combustors may be built someday (see Figure 1). These giants would be fed 240 tons of coal/hr (90% C, 10% H2), 50% of which would burn within the battery of primary fluidized beds, the other 50% elsewhere in the system. One suggested design would use a battery of 10 fluidized beds, each 10 m long, 4 m wide, and containing solids to a depth of 1 m. Find the rate of reaction within the beds, based on the oxygen used.

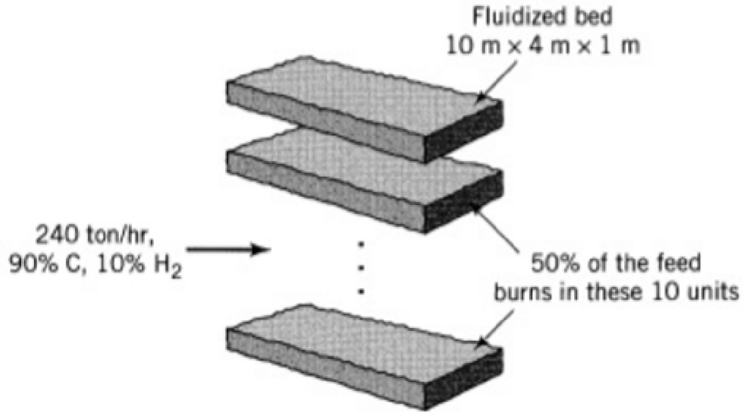


Figure 1: Design of fluidized bed combustors (source: Levenspiel's textbook)

Problem 2 (25 marks). The gas phase reactions

(1) $A \rightarrow B + 2C$ $\qquad -r'_{1A} = k_{1A} C_A^2,$ $\qquad \Delta H_{Rx1A} = -50\ kJ/molA$

(2) $C + 3A \rightarrow 2D$ $\qquad -r'_{2C} = k_{2C} C_A C_C,$ $\qquad \Delta H_{Rx2A} = +20\ kJ/molA$

(3) $E \rightarrow G$ $\qquad -r'_{3E} = k_{3E} C_E^2,$ $\qquad \Delta H_{Rx1A} = +80\ kJ/molA$

occur in a PBR with a heat exchanger. The PBR contains 500 kg of catalyst. The entering concentration of A is 0.8 mol/dm^3 and the entering concentration of E is 0.2 mol/dm^3. The entering volumetric flow rate is 10 dm^3/s at a temperature of 300 K. It was found that the rate for reactions (1) and (2) doubles for a 10 K increase from 300 to 310 in temperature while the rate of reaction (3) doubles for a 10 K increase from 500 K to 510 K. The entering pressure is 24.6 atm.

Additional Information

$$C_{P_A} = 60 \frac{J}{mol \cdot K} \qquad k_{1A} = 0.7 \frac{dm^3}{mol \cdot s} \text{ @ } 300\ K$$

$$C_{P_B} = 20 \frac{J}{mol \cdot K} \qquad k_{2C} = 3.8 \frac{dm^3}{mol \cdot s} \text{ @ } 300\ K$$

$$C_{P_C} = 20 \frac{J}{mol \cdot K} \qquad k_{1A} = 0.9 \frac{dm^3}{mol \cdot s} \text{ @ } 500\ K$$

$$C_{P_D} = 100 \frac{J}{mol \cdot K} \qquad \alpha = 0.0001\ kg^{-1}$$

$$C_{P_E} = 50 \frac{J}{mol \cdot K} \qquad C_{T_0} = 1.0 \frac{mol}{dm^3}$$

$$C_{P_A} = 60 \frac{J}{mol \cdot K} \qquad T_0 = 300\ K$$

$$\frac{Ua}{\rho_b} = 20 \frac{kJ}{s \cdot kg\ cat} \qquad T_a = 350\ K$$

Write a complete Polymath code which can be used to plot the temperature and species concentration as a function of catalyst weight. Include all necessary initial conditions.

Problem 3 (30 marks). The following reversible, elementary, liquid phase reaction occurs in a PFR:

$$A \leftrightarrows B$$

The entering flow rate is 10 dm^3/s with an entering concentration of 2 M of A and the feed temperature is 310 K.

a) What is the reactor volume necessary to achieve 90% of the adiabatic equilibrium conversion in one PFR operated adiabatically? (marks)
b) Is the reaction exothermic or endothermic? (marks)
c) Now consider a series of reactors with interstage cooling so that the temperature is cooled to 300 K in each interstage cooler. How many reactors are necessary to achieve 95% conversion assuming 99.9% of the equilibrium conversion is achieved in each reactor? (marks)

Additional information:

$$C_{P_A} = C_{P_B} = 50 \frac{cal}{mol \cdot K} \qquad \Delta H^0_{rxn} = -10000 \frac{cal}{mol\ A}$$

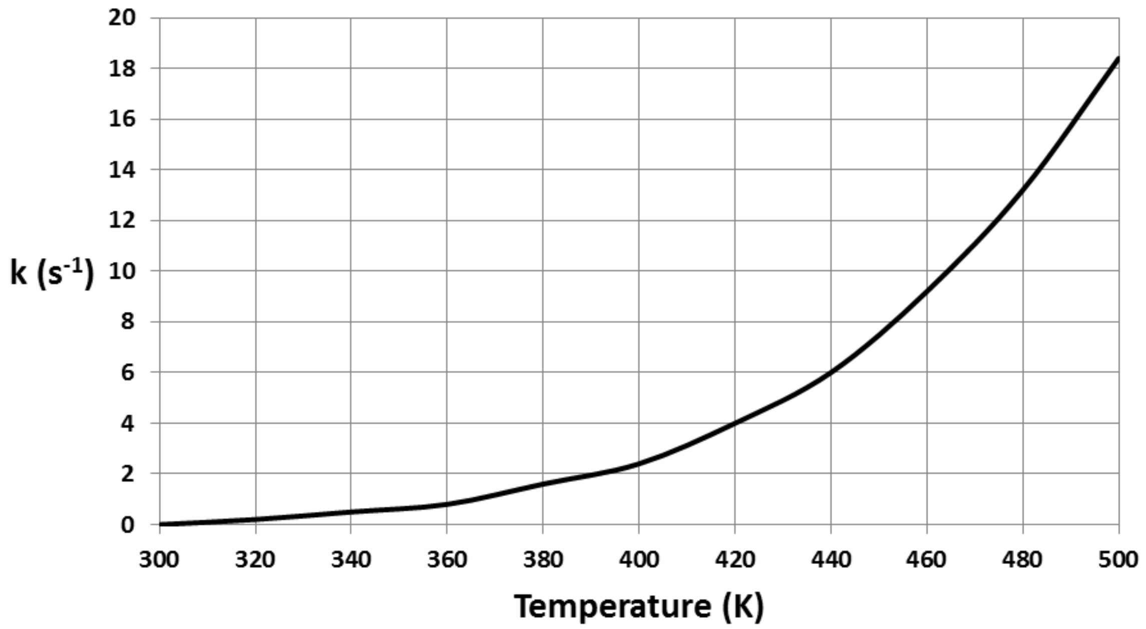
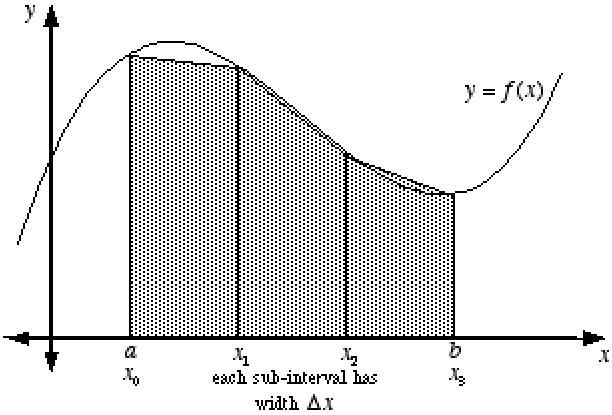


Figure 2: Specific rate vs temperature plot

Hint: Recall conversion vs reaction rate plots. You may find the trapezoidal rule (see Figure 3) useful in solving this problem. You may also find graph paper at the end of this booklet useful for plotting graphs.

Trapezoidal rule:



The area of the trapezoids (shaded) approximately equals the area bounded by $y = f(x)$.

$$\int_a^b f(x)dx = \frac{\Delta x}{2}\left[f(x_0) + 2f(x_1) + 2f(x_2) + f(x_3)\right].$$

Figure 3: Trapezoidal rule (source: http://www.mathwords.com/t/trapezoid_rule.htm)

Problem 4 (15 marks). The following sequence is believed to occur for the decomposition of ethane

$$C_2H_6 \xrightarrow{k_1} 2CH_3 \bullet$$

$$C_2H_6 + CH_3 \bullet \xrightarrow{k_2} C_3H_6 + 3H \bullet$$

$$H \bullet + H \bullet \xrightarrow{k_3} H_2$$

Develop a rate law for the rate of formation of propylene in terms of the concentration of ethane.

Problem 5 (15 marks). The first-order reversible liquid reaction

$A \leftrightarrows R,$ $\qquad C_{A0} = 0.5\frac{mol}{L},$ $\qquad C_{R0} = 0$

takes place in a batch reactor. After 8 minutes, conversion of A is 33.3% while equilibrium conversion is 66.7%. Find the rate equation for this reaction.